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LONG TERM SPACE ASTROPHYSICS RESEARCH PROGRAM

FINAL TECHNICAL REPORT FOR NAGW-2565

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Final Technical Report for NAGW-2565

"Accretion Processes in Cataclysmic Variables"

Joseph Patterson, Principal Investigator

This is the final report for NAGW-2565, "Accretion Processes in Cataclysmic Variables", spanning May 1, 1991 to April 30, 1997 (including the no-cost extension to a 6th year).

1. A BACKYARD ASTRONOMY NETWORK

A major part of this work, as proposed and executed, was the formation of a network of amateur astronomers for intensive photometry campaigns on individual cataclysmic variables. This succeeded tremendously, because over the 5-year period, the costs of computers and CCDs sharply plummeted – putting the required toys within reach of many more people. We now have a strong network of about 40 amateur and professional astronomers (the Center for Backyard Astrophysics), distributed over the Earth and operating in close concert when the occasion demands. This has given excellent ground-based observing support to space observations, both through observation exactly simultaneous with spacecraft, and through long-term ephemerides enabling us to specify exact orbital or rotational phase. Surprisingly, even though the telescopes are small (averaging about 35 cm), for periodic signals we usually reach sensitivity limits about 3–4 times better than professional astronomers achieve in a traditionally-scheduled observing run; this is because the telescopes are dedicated to a single task, often accumulating twenty times more data, enabling us to average over the flickering noise that is the principal bane of periodicity search. This network is flourishing now, has produced 22 published papers in refereed journals, and will surely be a great research resource for many years to come.

2. SUPERHUMP LIGHT VARIATIONS

The most recurrent, the most novel, and perhaps the most interesting theme of our work has been the study of "superhumps" in cataclysmic variables. We launched an extensive series of papers on this subject, now up to 12 with 4 more in the pipeline. When we started this work, these signals were known to be slightly unstable, with periods slightly displaced from the orbital period. Not much else was known. We organized enormous observing campaigns on individual stars, around-the-clock and around-the-year, enabling us to track the periodic signals for very long intervals. Here are some highlights of our results:

- discovery of superhump periods in 15 dwarf novae (11 known previously)
- discovery of superhump periods in 14 "permanent" superhumpers (3 known previously)

- discovery of a standard period-luminosity relation in the decline phase of superoutbursts
- discovery of beat frequencies ($\nu_{\rm orb} - \nu_{\rm sh}$) in 7 stars (1 known previously)
- discovery of sideband frequencies to the harmonics of superhumps in 5 stars (0 known previously)
- period stabilization of a dwarf nova superhump after $\sim$ 500 binary orbits
- discovery of negative superhumps in CVs ($P < P_{\rm orb}$) and especially in the SW Sex stars
- discovery of dwarf-nova cycles of unprecedented shortness in the double-degenerate binaries

3. ACCRETION DISK STRUCTURE

Mainly through superhump studies, we learned a lot about the accretion disks of CVs of short orbital period. We found the shortest $P_{\rm orb}$ yet found among dwarf novae (1.7 s shorter than the previous record holder!), and found waves in the light curve indicating a large accretion disk extending out to the 2:1 orbital resonance. This requires an extreme mass ratio, with $M_1/M_2 > 20$; this in turn implies that the secondaries are of very low mass, probably $< 0.04\ M_\odot$. These are probably the cataclysmic-variable equivalent of the whittled-down secondaries better known among binary radio pulsars and X-ray binaries. Such small masses also explain why these stars (the "WZ Sagittae stars") show accretion rates of $\sim 10^{15}$ g/s, about a factor of 6 lower than the minimum set by gravitational radiation losses in binaries with main-sequence secondaries.

We also found many superhump periods from the study of the accretion disks in CVs, including a large class of stars showing periods slightly shorter than $P_{\rm orb}$ (negative superhumpers). The latter are likely to result from the wobbling of accretion disks which come out of the orbital plane, as has been known for a long time in Hercules X-1. We do not yet have a theory for how those disks manage to come out of the plane, but it seems likely that this is mainly due to insufficient cleverness on our part. The disk wobble really seems to happen. One star shows simultaneous positive and negative superhumps, and the period changes in each signal are opposite in sign, suggesting that they arise from the two types of precessional motion available to a disk – apsidal advance and nodal regression.

In one superhumping star we detected a periodic skewness variation in the absorption lines, the most direct possible signature of the disk's eccentricity. And, most surprisingly, the phase of the skewness variation (but not the period) depended on place in the line profile – as if the major axes of the various "ellipses" at different disk radii were not aligned with each other. This could also be explained if a spiral structure in the disk were intimately involved in the line formation process.

Finally we also found evidence for a large, soft X-ray-absorbing cloud associated with the stream-disk impact point in WZ Sagittae. This cloud must extend at least 15 degrees, and more likely 30 degrees, above the disk plane. It's hard to understand how the cloud can extend so high since the amount of thermal support is sparse. Something to worry about in the future.

4. DQ HERCULIS STARS

Much effort was devoted to the structure of DQ Herculis stars, CVs containing a rapidly rotating, magnetic white dwarf. In 1994 we wrote a long review article summarizing our knowledge of these stars. Because the accretion is radially channeled by the magnetic field lines, the accretion energy is released in a very small region at the magnetic pole, with a very high effective temperature. Thus the energies are high (from the vacuum ultraviolet through hard X-ray) and most of the data comes from spacecraft. Some highlights of this program:

- discovery of strong ultraviolet/X-ray pulsations in YY Dra at 265 s
- discovery of X-ray pulsations in WZ Sge at 27.86 s
- discovery of the two-pole accretion geometry in YY Dra, RX J0558+5353, and RX J0028+5918
- derivation of accretion rates in DQ Her stars from study of the bolometric fluxes
- derivation of accretion torques from long-term $\dot{P}$ studies

5. ACCRETION RATES

A major goal was derivation of secure accretion rates for cataclysmic variables. The principal method involves the bolometric summation of accretion fluxes, followed by multiplication by $4\pi d^2$. Using primarily *IUE* and *ROSAT* flux measurements available through HEASARC, and adding 3500–7000 A fluxes available from our own measurements and the literature, we have spent nearly a year on this project. However, the results were basically consistent with the same effort I made in 1982–4 (ApJS 54, 443), so I have not yet prepared this for publication. Over the next year, I will obtain improved infrared fluxes, which will yield improved distances.

6. EDUCATION

A 5-year program offers great opportunity to involve students in research. Collaborations leading to publication occurred with graduate students Eric Gotthelf, Hayley Richman, Emily Sterner, Anouk Shambrook, Eugene Thomas, and Mike Eracleous. Many more undergraduates, 20–25 in all, were involved in the work, with publications resulting in about half the instances.

7. PUBLICATIONS

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